Fishery Data Series No. 06-62

Abundance and Length and Age Compositions of Arctic Grayling in the Pilgrim River, 2002

by

Andrew D. Gryska

November 2006

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_{2}, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA REPORT NO. 06-62

ABUNDANCE AND LENGTH AND AGE COMPOSITIONS OF ARCTIC GRAYLING IN THE PILGRIM RIVER, 2002

by
Andrew D. Gryska
Alaska Department of Fish and Game, Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

November 2006

Development and publication of this manuscript were partially financed by the Federal Aid in Sport fish Restoration Act(16 U.S.C.777-777K) under Project F-10-17, Job No. R-3-2(c).

The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

Andrew D. Gryska,
Alaska Department of Fish and Game, Division of Sport Fish,
1300 College Road, Fairbanks, AK 99701-1599 USA

This document should be cited as:
Gryska, A. D. 2006. Abundance and length and age composition of Arctic grayling in the Pilgrim River, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 06-62, Anchorage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Appendix **Page**

ABSTRACT

A mark-recapture experiment was conducted along a 9.0-km (5.5-mi) section of the Pilgrim River during August 2002 to estimate abundance and length and age composition of Arctic grayling *Thymallus arcticus*. The population in this index section is periodically assessed to ensure that it is sustained at or above a management-prescribed level of 350 fish ≥ 350 mm FL. This population was last assessed during 1996. Using hook-and-line gear and beach seines, 246 fish were captured. Using a pooled Bailey-modified Petersen estimator, abundance was estimated at 740 (SE = 145) Arctic grayling ≥ 270 mm FL and 580 (SE = 115) Arctic grayling ≥ 350 mm FL. Most (76%) captured fish ranged from 350 to 449 mm FL, and most (71%) fish were ≥ age-7.

Key words: Arctic grayling, *Thymallus arcticus*, abundance, age composition, length composition, hook-and-line, beach seine, mark-recapture, Pilgrim River, Alaska.

INTRODUCTION

The Seward Peninsula of western Alaska has many rivers and streams that are easily accessible by way of an extensive road system (approximately 420 km in length), which emanates from Nome (Figure 1). Most streams along this road system, including the Pilgrim River, support some angling effort for Arctic grayling *Thymallus arcticus* by many of the 9,200 residents of the Nome census area (U.S. Census Bureau 2001), as well as numerous tourists. The Pilgrim River is accessible from the Nome-Taylor Highway at its mouth at Salmon Lake and at milepost 65 where it crosses the river 51 km from its mouth. The Pilgrim River is approximately 99 km long, emanating from Salmon Lake in the Kigluaik Mountains. The river flows in a northerly direction from Salmon Lake until it crosses the Nome-Taylor Highway, where it heads west to the Kuzitrin River and the Imuruk Basin. Major tributaries of the Pilgrim River include the catchments of Salmon Lake and Crater and Iron creeks. The river contains populations of Arctic grayling, northern pike *Esox lucius*, burbot *Lota lota*, Dolly Varden *Salvelinus malma*, longnose sucker *Catostomus catostomus*, round whitefish *Prosopium cylindraceum*, humpback whitefish *Coregonus* pidschian, Chinook salmon *Oncorhynchus tshawytscha*, sockeye salmon *O. nerka*, pink salmon *O. gorbuscha*, chum salmon *O. keta*, and coho salmon *O. kisutch*.

Most of the sport fishing effort in the Pilgrim River drainage is directed at Arctic grayling, northern pike, Dolly Varden, and salmon (A. DeCicco, Sport Fish Biologist, retired, ADF&G, Fairbanks; personal communication). Fishing effort for Arctic grayling occurs at the Salmon Lake outlet, upstream and downstream of the bridge for several kilometers, and to a lesser extent between the Salmon Lake outlet and the bridge. From 1992 through 2002, the Pilgrim River averaged 790 angler days of fishing effort, 51 Arctic grayling harvested, and 573 Arctic grayling caught (Table 1; Mills 1993, 1994; Howe et al. 1995, 1996, 2001a-d; Walker 2003).

The Pilgrim River and many other Nome area streams are known for producing large Arctic grayling and a 15-in length restriction was implemented to afford some protection of these larger fish. In general, streams with roadside access have more stringent regulations (5 grayling/day and only one may be ≥ 15 in TL) than the background regulations that are applied to the remote streams of the Seward Peninsula (5 grayling/day and no size limit; formerly 10 grayling/day and no size limit prior to 2004). Since 1992, the Pilgrim River has had a bag limit of two Arctic grayling/day of which only one may be > 15 in TL (350 mm FL), and this regulation does appear to have reduced harvest (Table 1).

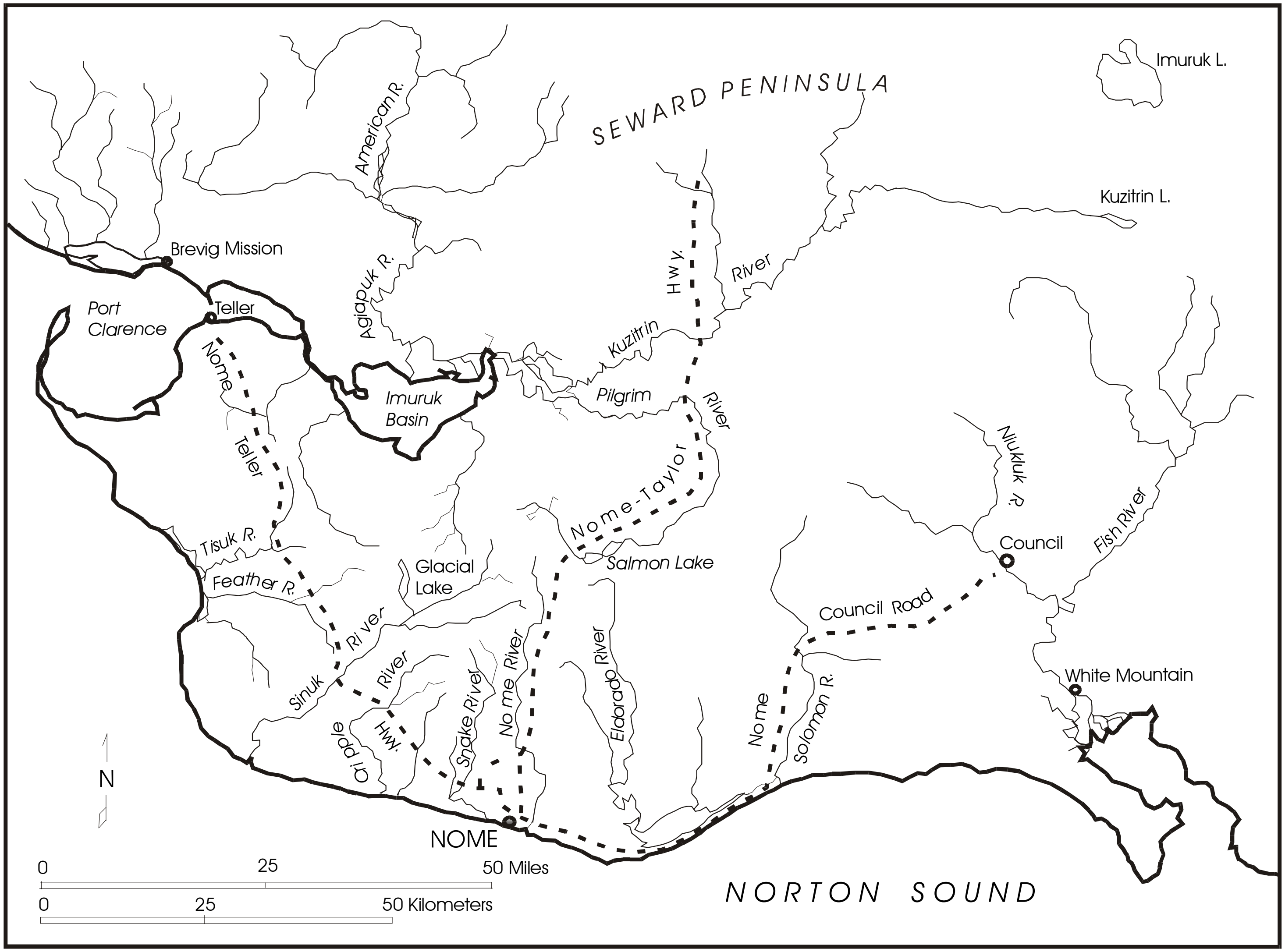

Figure 1.-Southern Seward Peninsula with road accessible waters.

Table 1.–Estimated numbers of anglers, days fished, and Arctic grayling catch and harvest for the Pilgrim River, 1988 – 2000.

Year[a]	Number of Anglers	Days Fished	Catch[b]	Harvest
1988	743	4,729		109
1989	1,017	1,645		516
1990	779	1,627	1,476	415
1991	1,133	3,085	4,463	445
1992[c]	686	1,184	526	91
1993	544	1,017	2,362	75
1994	310	808	266	49
1995	517	1,239	370	52
1996	445	840	821	73
1997	456	820	429	81
1998	392	546	65	0
1999	283	433	694	11
2000	177	753	221	58
2001	207	491	404	44
2002	303	562	144	31
		Averages		
1988-1991	918	2,772	2,970	371
1992-2002	393	790	573	51

Source: Data from the Alaska Statewide Harvest Survey (SWHS): Mills 1989-1994; Howe et al. 1995, 1996, 2001a-d.

[a] The 2000 – 2002 estimates (DeCicco 2004) are unofficial and unpublished because they were based on an insufficient number responses to the SWHS.

[b] No data are available for catch prior to 1990.

[c] Beginning 1992, the Pilgrim River has had a bag limit of two Arctic grayling/day of which only one may be > 15 in TL (350 mm FL).

From 1989 to 2000, concerted research was conducted on several important Arctic grayling populations on the Seward Peninsula (Merritt 1989; DeCicco 1990-1997, 2000, 2002a) that culminated in a fishery management plan for rivers with Arctic grayling along the Nome Road system and the current regulatory structure (DeCicco 2002b). In this plan, specific management objectives have been established for the Niukluk, Fish, Pilgrim, Nome, Snake, and Sinuk rivers (Figure 1), which prescribes minimum abundances of Arctic grayling (≥ 15 in TL) in index areas. The research program, as described in the management plan, recommends periodic population assessments for these and other road-accessible streams to ensure that abundances are being maintained at or above prescribed levels.

The Pilgrim River management objective is to maintain a minimum abundance of 350 Arctic grayling ≥ 15 in TL (350 mm FL) within a 9.0-km index area having an upper boundary at the Nome-Taylor Highway Bridge (Figure 2). This objective was established based on assessments conducted between 1990 and 1996 (Table 2). Due to the Pilgrim River's accessibility, sustained effort, and relatively small population, DeCicco (2002a) also recommended assessments of the Pilgrim River population be conducted every 5 years; however, prior to this study it had not been assessed for 6 years. Therefore, the goal of this study was to reassess the Arctic grayling population in the Pilgrim River in the 9-km index area to determine if the prescribed level of ≥350 Arctic grayling ≥ 15 in TL (350 mm FL) had been maintained.

OBJECTIVES

The project objectives were to estimate:

1. The abundance of Arctic grayling (≥ 270 and ≥ 350 mm FL) in a 9-km (5.5 mi) index area of the Pilgrim River, such that the estimate is within 25% of the actual abundance 90% of the time;
2. The length composition of Arctic grayling (≥ 270 mm FL) in a 9-km (5.5-mi) index area of the Pilgrim River, such that all estimated proportions (10-mm and 25-mm groups) are within 5 percentage points of the true proportions 95% of the time; and,
3. The age composition of Arctic grayling (≥ 270 mm FL) in a 9-km (5.5-mi) index area of the Pilgrim River, such that all estimated proportions (ages 1-6 and age-7+) are within 5 percentage points of the true proportions 95% of the time.

METHODS

SAMPLING DESIGN AND FISH CAPTURE

In 2002, the Pilgrim River Arctic grayling study was designed to estimate abundance and length and age composition of Arctic grayling within the 9-km index area by conducting a two-event mark-recapture experiment. The first (marking) event occurred during August 6-9 and the second (examination) event during August 12-15.

During each event, sampling began at the Nome-Taylor Highway Bridge and moved sequentially downstream. Each day, a crew (comprised of two people in the first event and three in the second event) expended approximately 8-hours of sampling effort (Appendix A1). During each event, a beach seine (50 m x 2 m, 6.5-mm mesh) and hook-and-line gear (fly-fishing and spin fishing) were used to capture fish. When angling, a variety of terminal gears were utilized, and they included size 12 – 16 flies and 1/8 and 1/16 ounce jigs having size 1 or 2 hooks, several colors of rubber bodies, and rubber salmon eggs. The choice of terminal gear was left to the discretion of each angler.

In the first event, fish ≥ 250 mm FL were given a primary mark with an individually-numbered anchor tag (Floy FD 94[1]). Additionally, a secondary mark (a partial upper caudal fin clip) was used to identify and mitigate effects of tag loss. In the second event, fish were not tagged, but a partial lower caudal fin clip was given to all captured fish to avoid double counting. Sample size objectives for the abundance estimate were established using methods in Robson and Regier (1964) and for compositions using criteria developed by Thompson (1987) for multinomial proportions.

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

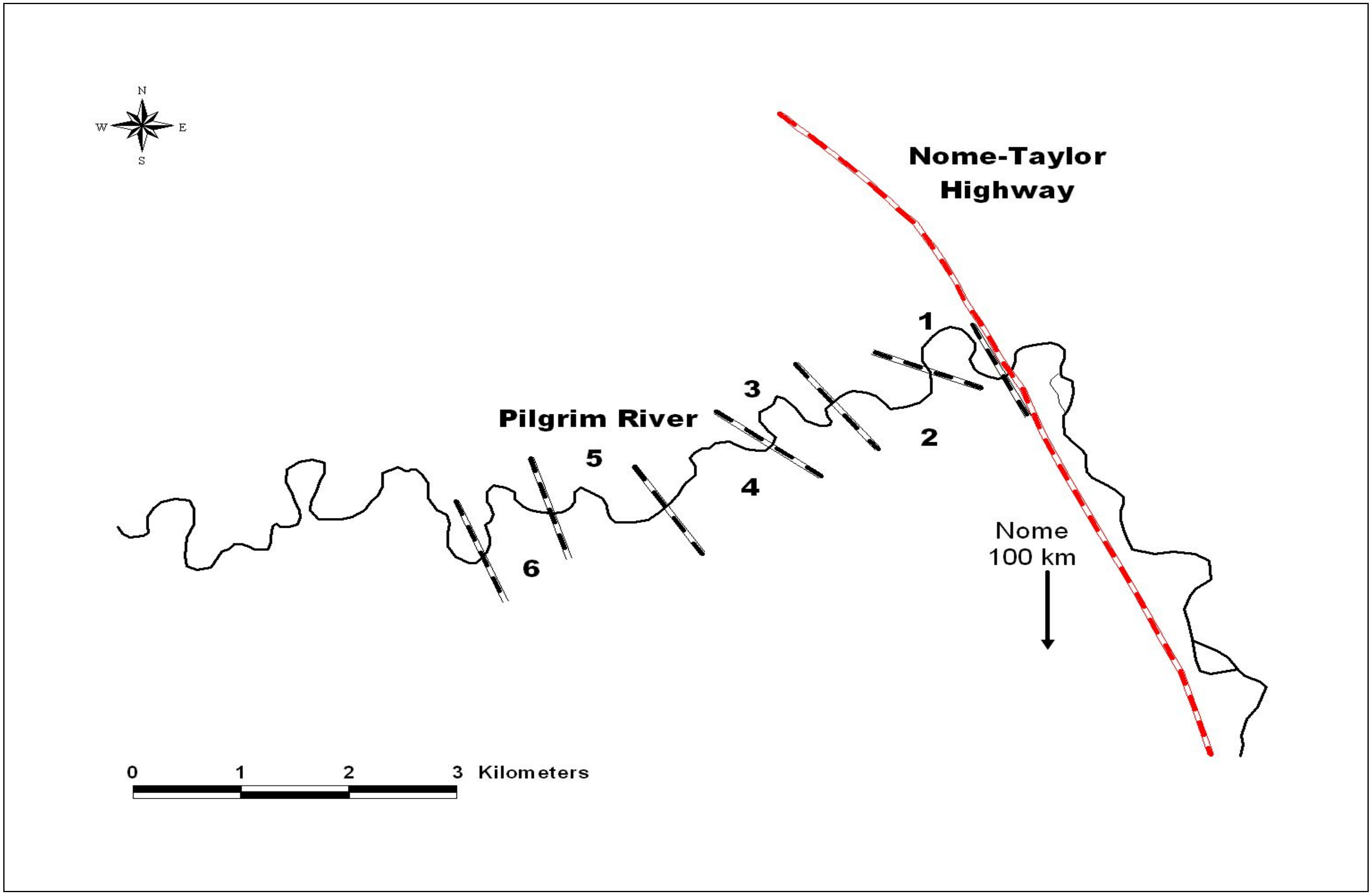

Figure 2.–Pilgrim River and study area with sections 1-6 demarcated.

Table 2.–Estimated abundance, SE, and number of fish/km for Arctic grayling ≥ 270 mm FL in the Pilgrim River 9-km index area during 1990, 1991, 1992, 1993, 1994, 1995 and 1996.

Year	Abundance	SE	Fish/km
1990	1,717	428	191
1991	1,152	210	128
1992	1,108	161	123
1993	595	83	66
1994	374	85	42
1995	657	117	73
1996	534	77	59

Source: Data from: DeCicco 1991-1997.

Abundance was estimated using a two-event Petersen mark-recapture experiment (Seber 1982) designed to satisfy the following assumptions:

1. The population was closed (Arctic grayling do not enter or leave the population during the experiment);
2. All Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between the first and second events;
3. Marking of Arctic grayling in the first event did not affect the probability of capture in the second event;
4. Marked Arctic grayling were identifiable during the second event; and,
5. All marked Arctic grayling were reported when examined during the second event.

The estimator used was a modification of the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \qquad (1)$$

where:

n_1 = the number of Arctic grayling marked and released during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

m_2 = the number of marked Arctic grayling recaptured during the second event.

The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met.

The sampling design allowed the validity of these assumptions to be ensured or tested. To help ensure that the movement of fish did not violate the assumption of closure, the experiment was conducted during the summer feeding period when Arctic grayling were not expected to be migrating (Tack 1973; Ridder 1998; Ridder and Gryska 2000; Gryska 2001). Movement was expected but only on a localized scale (e.g., up to 2 river km). The duration of the study was kept short to render growth recruitment and mortality insignificant. Location data for recaptured fish were examined for evidence of movement to evaluate the appropriateness of the assumption of closure.

To ensure that Assumption 2 was met, an attempt was made to subject all fish during each sampling event to the same probability of capture by sampling each pool and run with effort in proportion to the distribution of Arctic grayling. Specifically, more time was spent in locations where numerous fish were encountered than in areas where few fish were encountered as determined by visual sightings, strikes, and catches. In general, densities appeared relatively high in glides and pools and lower in slack water areas and riffles. Because Arctic grayling move little during mid-summer, complete mixing of marked and unmarked fish within the study area was not expected; rather Arctic grayling were expected to mix within approximately 2 km reaches. Diagnostic tests to identify heterogeneous capture probabilities and methods to correct for potential biases are presented in the Data Analysis section.

Relative to Assumption 3, a hiatus of four days between the first and second events in a given river section was included to allow marked fish the time to recover from the effects of being captured and handled and to resume their normal behavior. In addition, the use of active gear and two different types of terminal gear when angling served to mitigate potential marking-induced effects in behavior (e.g., gear avoidance).

Relative to Assumptions 4 and 5, Arctic grayling captured during the first event were double-marked with an internal anchor tag and a fin clip, and all fish caught in the second event were carefully examined for marks.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or very near their capture location. After each fish was caught, crews recorded the date, location, fork length, old fin clips, tag number, tag color, recapture status, and mortality (if that occurred) onto a coin envelope and into a field notebook. To determine the age of each fish, two scales were removed from each fish in area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin (W. Ridder, Sport Fish Biologist, retired, ADF&G, Delta Junction; personal communication; Brown 1943), and stored in its respective coin envelope. These data were later entered into an Excel spreadsheet for analysis and archival (Appendix B1). Floy tags were gray and were numbered between 11,377 and 11,434 and between 11,436 and 11,513.

In the lab after completion of field sampling, scales were processed by wiping slime and dirt off each scale and mounting them on gummed cards. The gummed cards were used to make triacetate impressions of the scales (30 s at 137,895 kPa, at a temperature of 97ºC). Ages were determined by counting annuli from the triacetate impressions magnified to 40x with a microfiche reader. The presence of an annulus was determined as described by Kruse (1959).

DATA ANALYSIS

Abundance Estimate

The specific form of the Petersen estimator was determined from the results of diagnostic tests. Violations of Assumption 2 relative to size effects were tested for using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix B1.

To check for spatiotemporal differences in capture probability, tests for consistency of the Petersen estimator (Seber 1982) were performed and the appropriate estimator selected (Appendix C2). The sample area was divided into six sections of approximately 1.5 km in length to provide a minimum scale at which capture probabilities could be examined (Figure 2). Criteria considered when defining geographic strata included number of recaptures per stratum, hydrology, and stratum length relative to anticipated movements. When estimating abundance a minimum number of recaptures (approximately 7 fish) were preferred to permit reliable diagnostic testing and to ensure negligible statistical bias in $\hat{N}$ (Seber 1982). Sections longer than approximately 2 km were preferred to accommodate localized movements of Arctic grayling (e.g., approximately 1-2 km). Documentation of release location for each fish permitted the examination of multiple geographic stratification schemes for purposes of assumption testing.

Length and Age Compositions

Length and age composition of the population were estimated using the procedures outlined in Appendices C1 and C3.

RESULTS

SUMMARY STATISTICS OF FISH SAMPLED

Two hundred forty-six Arctic grayling (≥ 250 mm FL) were captured. Of the 245 fish ≥ 270 mm FL, 141 were captured during the first event (marked or n_1), 104 during the second event (examined or n_2), and 19 fish were marked in the first event and recaptured in the second event (recaptured or m_2). The smallest Arctic grayling marked during the first event was 283 mm FL, examined during the second event was 265 mm FL, and recaptured was 329 mm FL. The largest Arctic grayling caught was 496 mm FL. Hook-and-line gear captured 70 Arctic grayling, and seine gear caught 176 Arctic grayling. However, seine gear was abandoned during the second event due to a large number of spawning chum salmon *Oncorhynchus keta* fouling the net.

ABUNDANCE ESTIMATES

The estimated abundance of Arctic grayling ≥270 mm FL was 740 fish (SE = 145), and the estimated abundance of Arctic grayling ≥ 350 mm FL was 580 fish (SE = 115). The sampling design and the results of the testing procedures (Appendices B1 and B2) determined that stratification by size or area was not required. Therefore, the Bailey modified Petersen estimator (Bailey 1951, 1952) was used to estimate abundance of Arctic grayling ≥ 270 and ≥ 350 mm FL (Appendix B4). The use of the Bailey-modified Peterson estimator was appropriate because fishing occurred in a systematic downstream progression while attempting to subject all fish to the same probability of capture.

Although the smallest recaptured Arctic grayling was 329 mm FL, the 270-mm lower boundary defined in the objectives was retained because: 1) fish as small as 283 mm FL in the first event and 265 in the second event were sampled demonstrating that Arctic grayling larger than 270 mm FL were recruited to the gear; 2) the same gear was used to catch fish as small as 159 mm FL in experiments on the Pilgrim River in the early 1990s (DeCicco 1993); 3) K-S diagnostic tests (see below) did not reject the hypothesis of equal probability of capture regardless of size for Arctic grayling ≥ 270 mm FL; 4) using the estimated probability of capture during the second event, there was a relatively high probability (33%) that none of the marked fish < 229 mm FL (n = 8) would have been recaptured during the second event; and, 5) it was the smallest length at which all previous estimates for Pilgrim River Arctic grayling are comparable. The estimate of fish ≥ 350 mm FL was presented because it corresponds to a 15-in TL management objective and regulation.

Size stratification was not necessary because K-S tests indicated that the length composition of fish ≥ 270 mm FL marked in the first event did not differ significantly from fish examined in the second event (D = 0.09; P-value = 0.61) or from fish recaptured during the second event (D = 0.17; P-value = 0.64; Figure 3).

The tests of consistency were conducted at the smallest geographic scale (six sections each 1.5 km in length). At this scale, mixing of fish between sections was not complete (P-value < 0.01; Table 3), first event capture probabilities were equal between sections (P-value = 0.65; Table 4), and the second event capture probabilities were equal by section (P-value = 0.11; Table 5). Although the tests failed to reject the hypothesis of equal capture probabilities during each event (suggesting Assumption 2 was satisfied), the actual capture probabilities were variable and the tests had little power to detect differences due to an inadequate number of recaptures in most sections. Therefore, other geographic stratification schemes were examined and in all cases the tests failed to reject equal probability of capture during either event. The hypothesis of complete mixing was rejected in all cases. For example, diagnostic test results for the stratification scheme where adjacent sections were paired (three sections each 3 km in length) were as follows: mixing of fish between sections was not complete (P-value < 0.01; Table 6), first event capture probabilities were equal (P-value = 0.77; Table 7), and second event capture probabilities were equal (P-value > 0.99; Table 8).

Of the 19 fish with known release and recapture locations, 13 (68%) were recaptured within the same section in which they were marked. Of the six fish that moved outside their original marking section, three moved upstream and three downstream, and only two of the six fish moved more than two 1.5-km sections (Table 3).

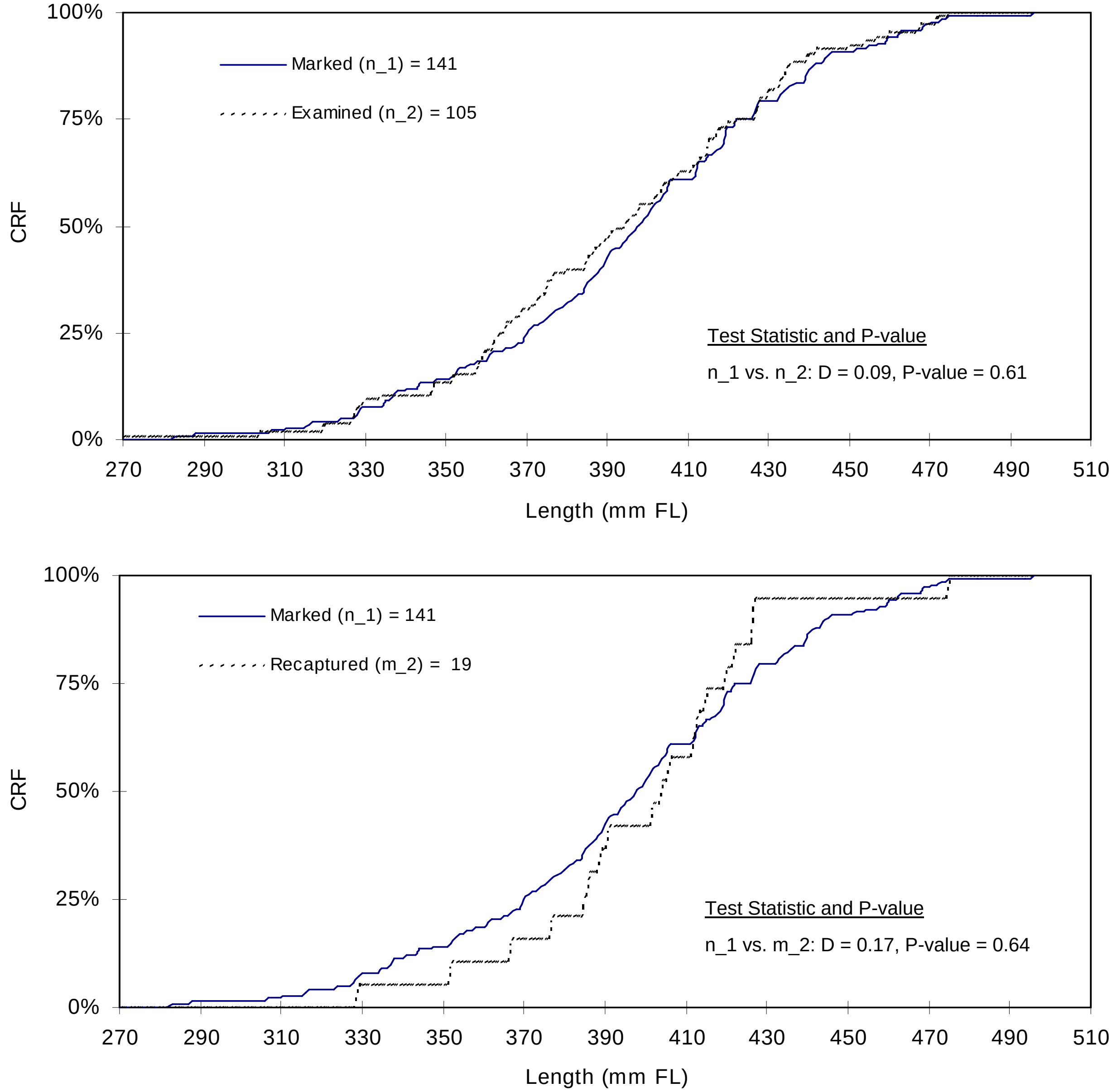

Figure 3.–Cumulative relative frequency (CRF) of Arctic grayling ≥ 270 mm FL marked and examined (upper panel) and marked and recaptured (lower panel), Pilgrim River, August 2002.

Table 3.–Test for complete mixing. Number of Arctic grayling ≥ 270 mm FL marked in each 1.5 km section (1 - 6) and recaptured or not recaptured in each section of the Pilgrim River, August 2002.

Section Where Marked	Section Where Recaptured 1	2	3	4	5	6	Not Recaptured (n_1-m_2)	Marked (n_1)
1	1						3	4
2							3	3
3			1			2	23	26
4				6		1	41	48
5				2	1		43	46
6				1		4	9	14
Total	1	0	1	9	1	7	122	141

χ^2 = 51.47; df = 20; P-value < 0.01; reject H_0.

Table 4.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 270 mm FL examined during the second event by 1.5 km section (1 – 6) of the Pilgrim River, August 2002.

Category	Section Where Examined 1	2	3	4	5	6	All Sections
Marked (m_2)	1	0	1	9	1	7	19
Unmarked (n_2-m_2)	5	3	1	46	9	22	86
Examined (n_2)	6	3	2	55	10	29	105
$P_{capture}$ 1st Event (m_2/n_2)	0.17	0.00	0.50	0.16	0.10	0.24	0.18

χ^2 = 3.31; df = 5; P-value = 0.65; fail to reject H_0.

Table 5.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 270 mm FL marked by 1.5 km section (1 - 6) during the first event that were recaptured and not recaptured during the second event, Pilgrim River, August 2002.

Category	Section Where Marked 1	2	3	4	5	6	All Sections
Recaptured (m_2)	1	0	3	7	3	5	19
Not Recaptured (n_1-m_2)	3	3	23	41	43	9	122
Marked (n_1)	4	3	26	48	46	14	141
$P_{capture}$ 2nd Event (m_2/n_1)	0.25	0.00	0.12	0.15	0.07	0.36	0.13

χ^2 = 8.90; df = 5; P = 0.11; fail to reject H_0.

Table 6.-Test for complete mixing. Number of Arctic grayling ≥ 270 mm FL marked in each 3 km section and recaptured or not recaptured in each section of the Pilgrim River, August 2002.

	Section Where Recaptured				
Section Where Marked	1&2	3&4	5&6	Not Recaptured (n_1-m_2)	Marked (n_1)
1 & 2	5	3		52	60
3 & 4	3	7		64	74
5 & 6			1	6	7
Total	8	10	1	122	141

χ^2 = 21.01; df = 6; P-value < 0.01; reject H_0.

Table 7.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 270 mm FL examined during the second event by 3 km section of the Pilgrim River, August 2002.

	Section Where Examined			
Category	1&2	3&4	5&6	All Sections
Marked (m_2)	8	10	1	19
Unmarked (n_2-m_2)	30	47	8	85
Examined (n_2)	38	57	9	104
$P_{capture}$ 1st Event (m_2/n_2)	0.21	0.18	0.11	0.18

χ^2 = 0.53; df = 2; P-value = 0.77; fail to reject H_0.

Table 8.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 270 mm FL marked by 3 km section during the first event that were recaptured and not recaptured during the second event, Pilgrim River, August 2002.

	Section Where Marked			
Category	1&2	3&4	5&6	All Sections
Recaptured (m_2)	8	10	1	19
Not Recaptured (n_1-m_2)	52	64	6	122
Marked (n_1)	60	74	7	141
$P_{capture}$ 2nd Event (m_2/n_1)	0.13	0.14	0.14	0.13

χ^2 = 0.01; df = 2; P > 0.99; fail to reject H_0.

LENGTH AND AGE COMPOSITIONS

The K-S tests indicated there was no size-selective sampling during either count (Case I scenario; Appendix B1); therefore, population compositions of lengths and ages were estimated using measurements from both sampling events. Most (76%) of the estimated population ranged between 350 and 449 mm FL (Table 9). Ages were obtained from 201 of 245 (82%) fish sampled for age, and they ranged from age-3-13 (Table 10). Most (71%) of the estimated population was age-7 or older.

Table 9.-Estimates of length composition and abundance by 10-mm FL groups for Arctic grayling ≥ 270 mm FL, Pilgrim River, August 2002.

Length Class	Based on Estimate ≥ 270 mm FL					Based on Estimate ≥ 350 mm FL				
(mm FL)[a]	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$CV[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$CV[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
270 – 279	0	0		0.00	0.00					
280 – 289	7	5	0.72	0.01	0.01					
290 – 290	3	3	1.00	<0.01	<0.01					
300 – 309	3	3	1.00	<0.01	<0.01					
310 – 319	13	7	0.53	0.02	0.01					
320 – 329	33	12	0.36	0.04	0.01					
330 – 339	26	10	0.39	0.04	0.01					
340 – 349	23	10	0.42	0.03	0.01					
350 – 359	33	12	0.36	0.04	0.01	30	11	0.36	0.05	0.02
360 – 369	56	17	0.30	0.08	0.02	51	15	0.30	0.09	0.02
370 – 379	66	19	0.29	0.09	0.02	60	17	0.29	0.10	0.02
380 – 389	59	17	0.30	0.08	0.02	54	16	0.30	0.09	0.02
390 – 399	72	20	0.28	0.10	0.02	66	19	0.28	0.11	0.02
400 – 409	62	18	0.29	0.08	0.02	57	17	0.29	0.10	0.02
410 – 419	66	19	0.29	0.09	0.02	60	17	0.29	0.10	0.02
420 – 429	56	17	0.30	0.08	0.02	51	15	0.30	0.09	0.02
430 – 439	49	15	0.31	0.07	0.02	45	14	0.31	0.08	0.02
440 – 449	43	14	0.33	0.06	0.02	39	13	0.33	0.07	0.02
450 – 459	23	10	0.42	0.03	0.01	21	9	0.42	0.04	0.01
460 – 469	29	11	0.38	0.04	0.01	27	10	0.38	0.05	0.02
470 – 479	16	8	0.48	0.02	0.01	15	7	0.48	0.03	0.01
480 – 489	0	0		0.00	0.00	0	0		0.00	0.00
490 – 499	3	3	1.00	<0.01	<0.01	3	3	1.00	0.01	0.01
Total	740	145	0.20	1.00	-	580	115	0.20	1.00	-

[a] Composition estimates were calculated using the abundance estimate for Arctic grayling ≥ 270 mm because abundance of fish 270-349 mm was of interest. However, composition estimates of Arctic grayling ≥ 350 mm do not sum to 580, the estimate of abundance for that size category, due to slight differences in capture probabilities between small and large fish.

Table 10.-Estimates of age composition and abundance by age class for Arctic grayling ≥ 270 mm FL, Pilgrim River, August 2002.

Age Class[a]	Range (mm FL) Minimum	Mean	Maximum	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
3	292	292	292	4	4	<0.01	<0.01
4				0	0	0.00	0.00
5	307	362	472	62	19	0.08	0.02
6	283	374	457	151	36	0.20	0.03
7+	320	405	496	523	105	0.71	0.03

[a] The scales from 191 of the 245 (78%) Arctic grayling sampled were readable and assigned an age.

DISCUSSION

The 2002 estimate of abundance of Arctic grayling ≥ 350 mm FL (580 fish; 90% confidence interval (CI) 391 - 769) was within the range of variability of previous estimates (Figure 4), and it significantly exceeded the management objectives of 350 Arctic grayling ≥ 350 mm FL. Movements of recaptured fish, relative to the small study area, indicated a potential for significant positive bias due to combined immigration and emigration at the boundaries; however, even if the bias was large (e.g., 25%), abundance still exceeded the management goal. Current regulations appear sufficient for maintaining abundance and composition of the population of Arctic grayling in the Pilgrim River at satisfactory levels relative to the management objective. Therefore, no management actions are recommended to reduce harvest.

Interestingly, there was no obvious increase in the abundance of fish despite two favorable conditions: a reduction in harvests and an increase in stream productivity. At the beginning of the 1992 season, the bag and possession limit was reduced from 5 Arctic grayling per day with only one ≥ 15 in TL (350 mm FL) to 2 fish per day with only one ≥ 15 in TL which presumably accounted for the substantial reduction in harvests after 1991 (Table 1). Between 1997 and 2001, Salmon Lake in the Pilgrim River’s headwaters was fertilized to increase primary production for enhancement of the sockeye salmon *O. nerka* population, which also likely increased downstream productivity. (G. Todd, Fishery Biologist, ADF&G, Nome; personal communication). Although these favorable conditions prevailed, the observed variability in the abundance and composition estimates may be explained by other factors, including episodic recruitment and the small size of the index area.

Variable recruitment can obscure or exacerbate differences in population parameters that may have resulted from changes in regulations or indicate differences when regulation changes had little or no effect (Allen and Pine III 2000). In Seward Peninsula streams, it has been hypothesized that the occurrence of favorable water conditions can be relatively infrequent or episodic, which results in a particularly strong cohort that can effectively sustain the population of long-lived fish (A. DeCicco, Sport Fish Biologist, retired, ADF&G, Fairbanks; personal communication). Recruitment of Arctic grayling is highly dependent on favorable water conditions for a period (e.g., 2-3 weeks) after hatching and emergence as well as for rearing (Armstrong 1986; Clark 1992). Evidence of episodic recruitment has been observed in the Snake River in the early 1990s (Gryska 2004) and in this study evidence of dominant cohorts was observed in the Pilgrim River. Two strong cohorts, age-4 in 1992 and 1994, are depicted in

Figures 5 and 6. As these fish aged through the mid-1990s, they are evident among each year's age compositions, as well as the length compositions although more obscurely due to indiscrete size-at-age (Figures 7 and 8; Appendix D). These larger cohorts were recruited to the fishery just after regulations were changed to reduce harvest, and this combination may have been influential to the increase in the proportion of larger, older fish observed after 1992.

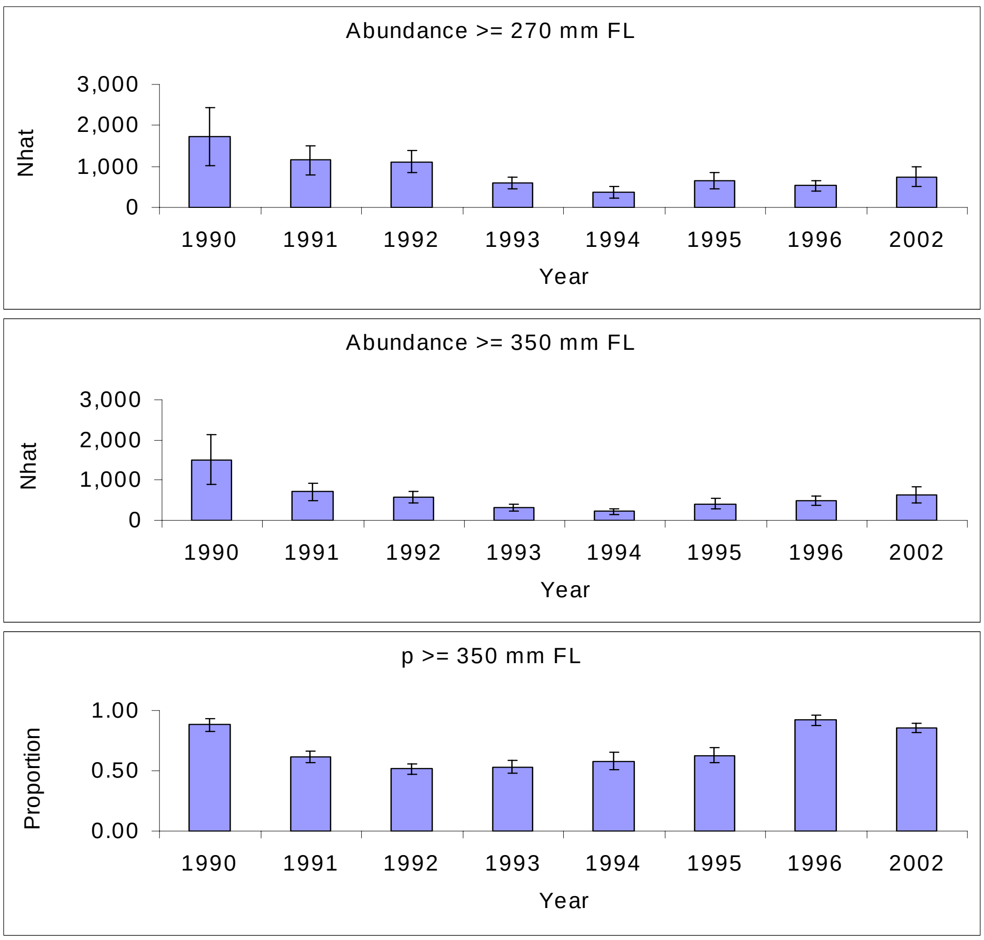

Figure 4.–Abundance and 90% CI of Arctic grayling ≥ 270 mm FL (upper panel), ≥ 350 mm FL (middle panel), and proportion ≥ 350 mm FL (lower panel) during 1990 – 1996 and 2002, in the Pilgrim River index area.

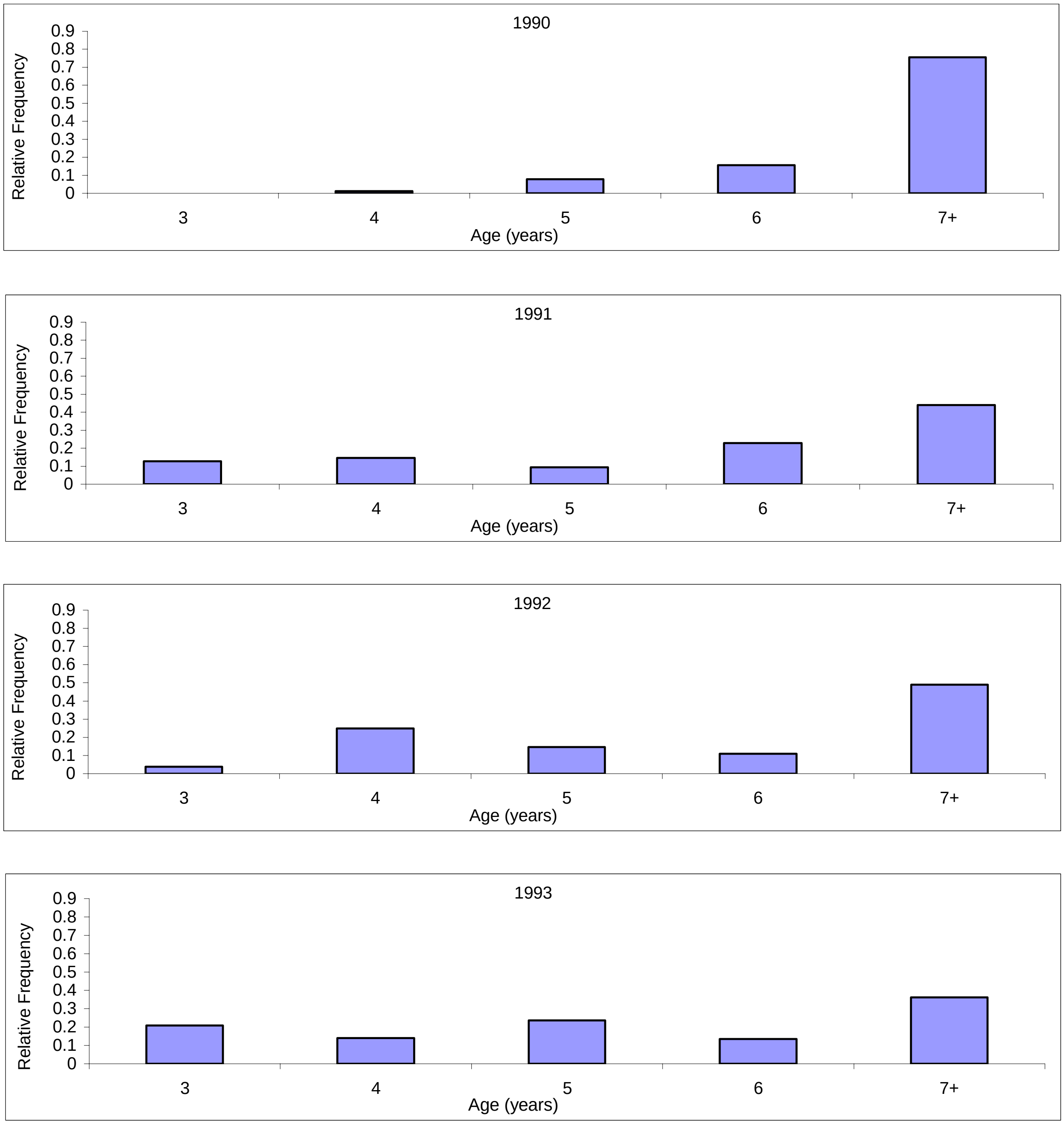

Figure 5.–Relative frequency distribution of the age composition of Arctic grayling ≥ 270 mm FL during 1990 – 1993 in the Pilgrim River index area.

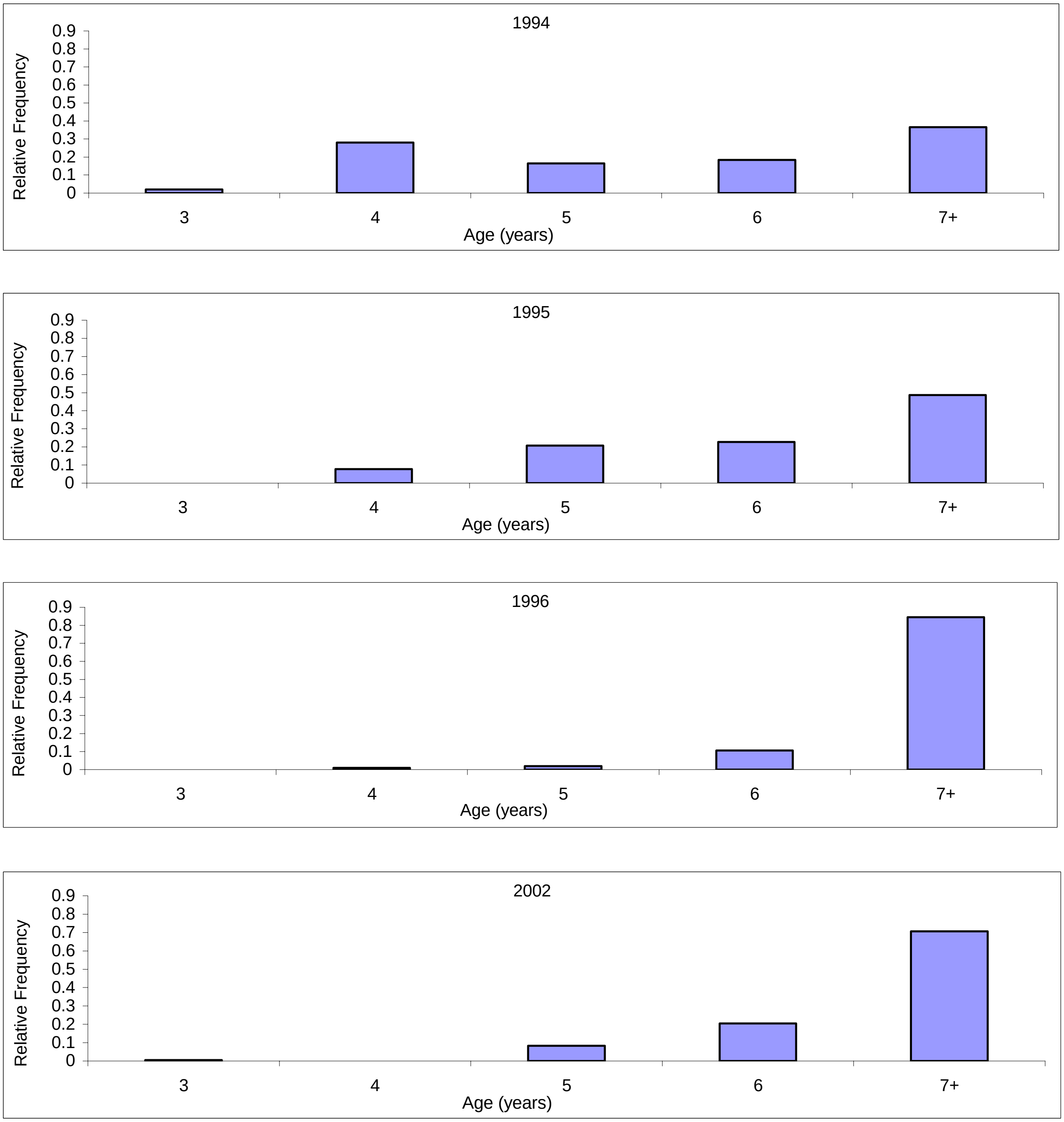

Figure 6.–Relative frequency distribution of the age composition of Arctic grayling ≥ 270 mm FL during 1994 – 1996 and 2002, in the Pilgrim River index area.

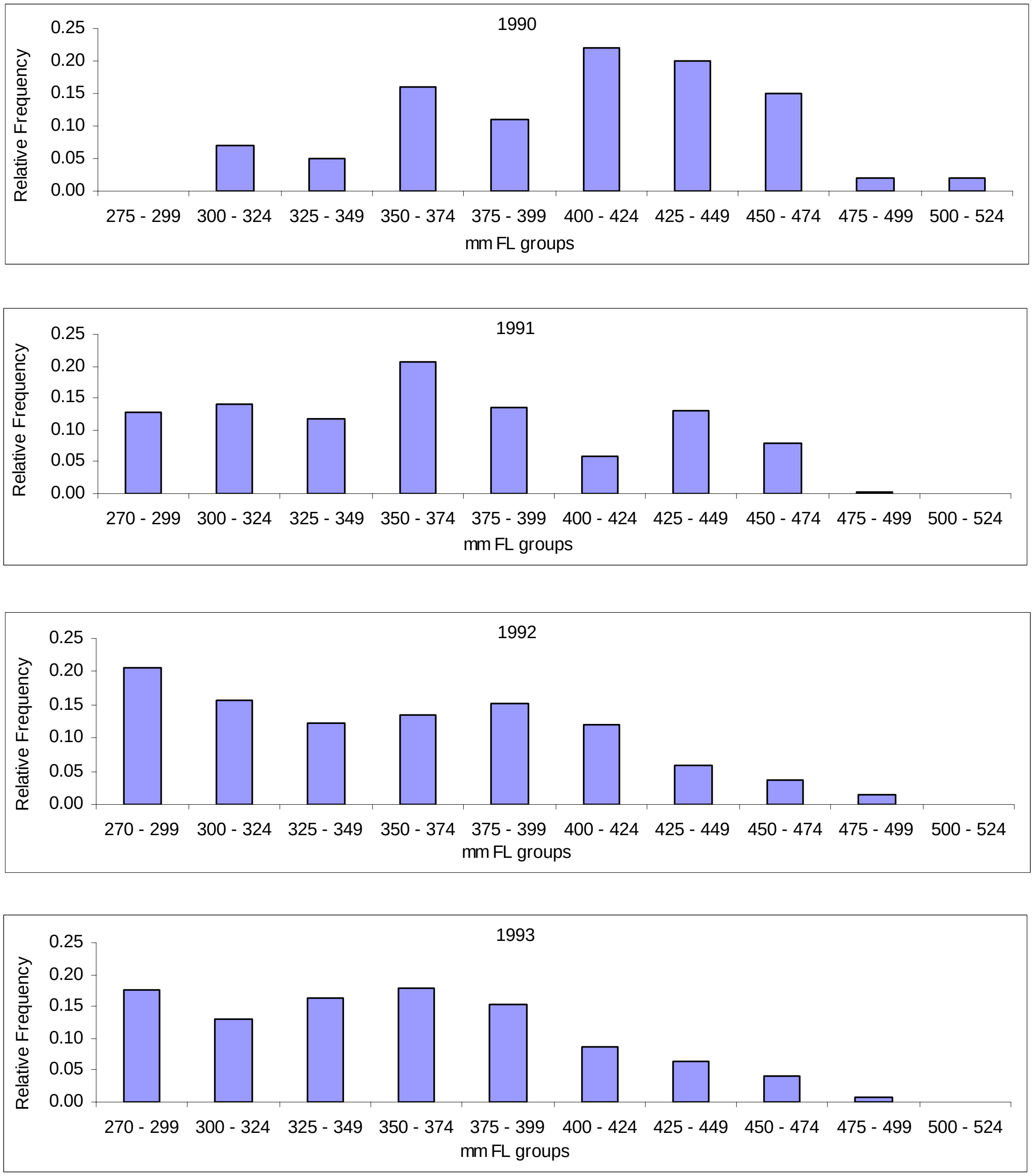

Figure 7.–Relative frequency distribution of the length composition of Arctic grayling ≥ 270 mm FL during 1990 – 1993 in the Pilgrim River index area.

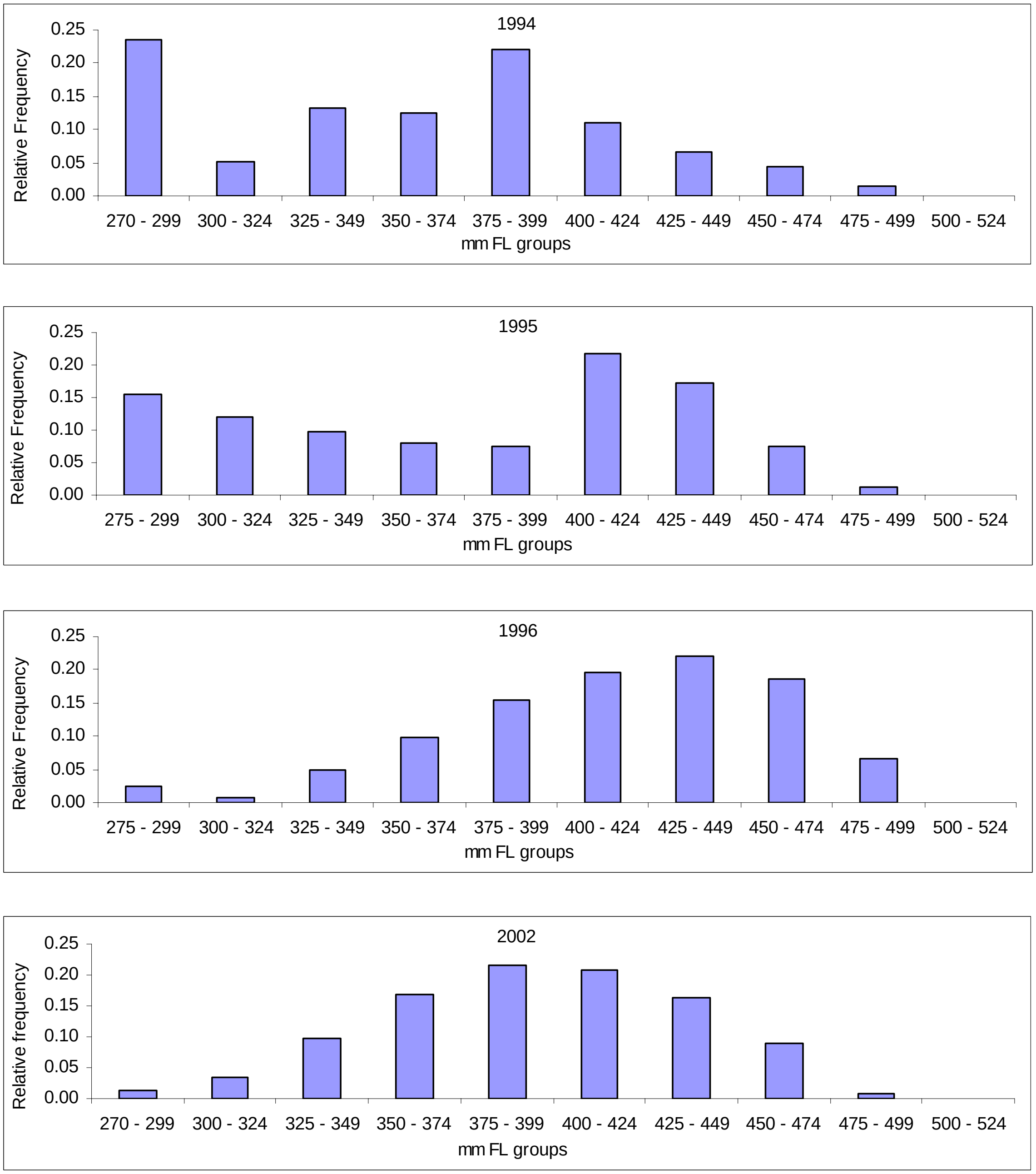

Figure 8.–Relative frequency distribution of the length composition of Arctic grayling ≥ 270 mm FL during 1994 – 1996 and 2002, in the Pilgrim River index area.

Because the index area was very short (9 km) relative to the 57 km of preferred Arctic grayling habitat (pool-riffle) available below Salmon Lake, seasonal and annual variations in the distribution of fish within the drainage would compromise the representativeness of the index area to the Pilgrim River population of the preferred area. Arctic grayling distribute themselves differently annually and seasonally based on water conditions (temperatures, discharge, and turbidity) and available forage (e.g., availability of pink salmon eggs during biannually weak and strong run cycles; Armstrong 1986; DeCicco 1995; Gryska *In prep*; Northcote 1995; Ridder 1998; Tack 1980).

An evaluation of whether the index area provides estimates of abundance and composition that are representative of the Pilgrim River population is needed to ensure erroneous management decisions are not made. Without assurance that a low abundance estimate from the index area is representative of the population, a manager may delay action pending a second and more comprehensive assessment or may unnecessarily impose a more restrictive regulation. Prior to such a predicament, it is recommended that a comprehensive assessment be conducted to evaluate the representativeness of the index area. This would be best accomplished by conducting a stock assessment and examining fish distributions from the outlet of Salmon Lake to the downstream end of the present study area. From that assessment, a larger representative index area could be drawn, if deemed necessary.

A clarification of the management objective is recommended to aid in interpretation of the abundance estimate relative to the management goal and in the design of future research projects. Currently, the management objective (350 Arctic grayling ≥ 350 mm FL) is not explicit about whether to use the lower boundary of the CI or the point estimate to define whether the objective was met. Further, if the point estimate is to be used, there needs to be an explicit statement of what level of precision is acceptable (i.e., 25% relative precision at the 90% confidence level). For example, a point estimate of 280 fish with 25% relative precision would have a 90% CI of 209 – 351, and the management plan does not unambiguously indicate whether this research finding would stimulate management action. Conversely, it is unknown if a point estimate of 351 fish with the same relative precision as achieved in this study (± 32.7%) would warrant a management action.

An unambiguous management objective would also be beneficial for planning future assessments and their sample size needs, because as demonstrated (Figure 9), the precision required to meet management goals will generally differ from typical "research precision" (relative precision of 25% at either the 90 or 95% confidence levels). For a Pilgrim River Arctic grayling population abundance exceeding 467 fish, a management goal can be met with precision and sample sizes less than typically required for research objectives; but if abundance is less than 467 Arctic grayling, then precision and sample size must increase dramatically to ensure the lower range value of the CI is ≥ 350. In this study, management goals were adequately addressed even though the precision expectations for the abundance estimates were not achieved (for Arctic grayling ≥ 350 mm FL the abundance estimate's relative precision at the 90% confidence level was ± 32.7% and for Arctic grayling ≥ 270 mm FL it was ± 32.3%). To have attained estimates within research precision would have required more samples provided by more fishing effort. By clarifying the management objective, the necessity of additional and more costly sampling could be evaluated, whether for attaining "research precision" or for ensuring a CI will exceed the management objective.

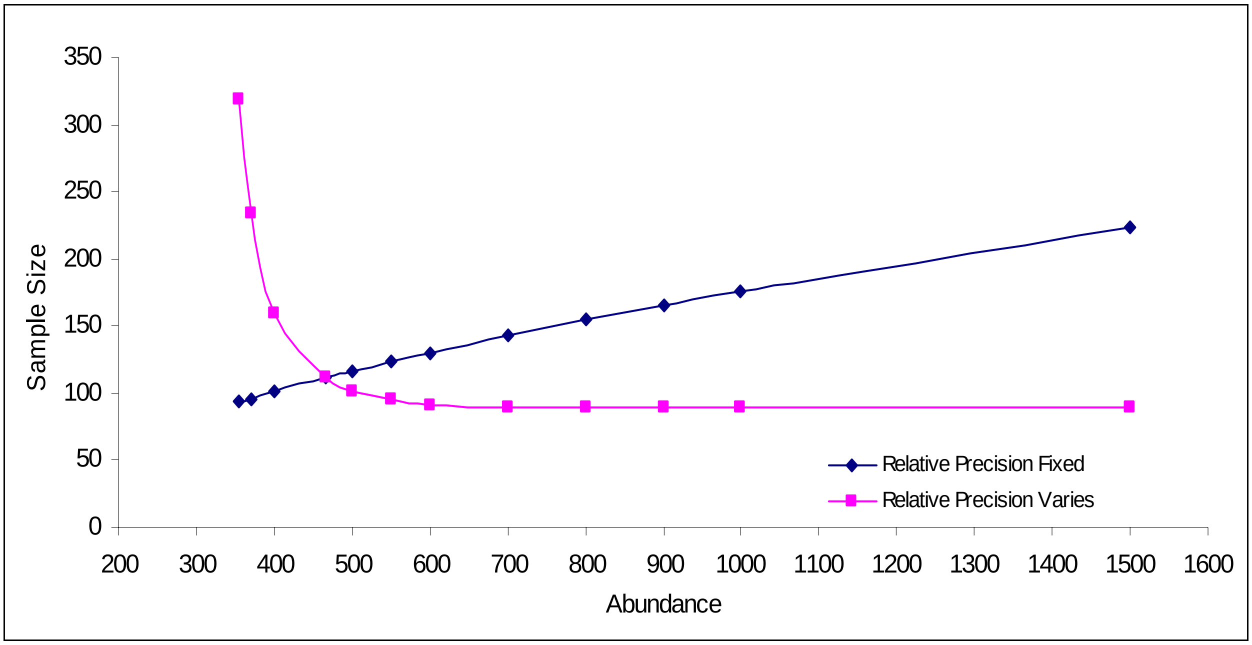

Figure 9.–Sample sizes needed to estimate a given abundance of a population with a relative precision of 25% ($\alpha = 0.1$) and with a relative precision that varies but ensures that the 90% CI has a lower limit of 350.

ACKNOWLEDGEMENTS

The author thanks Alfred DeCicco, Dave Stoller, and Jenny Neyme for their assistance in sampling. Their enthusiasm and abilities in capturing fish were much appreciated. Also, thanks to Don Roach, Matt Evenson, and Klaus Wuttig for their supervisory support, Sara Case for the editing and formatting of this report for publication, and Brian Taras for his biometric review.

REFERENCES CITED

Allen, M. S., and W. E. Pine III. 2000. Detecting fish population responses to a minimum length limit: Effects of variable recruitment and duration of evaluation. North American Journal of Fisheries Management 20:672-682.

Armstrong, R. H. 1986. A review of Arctic grayling studies in Alaska, 1952–1982. Biological Papers of the University of Alaska No. 23.

Bailey, N. T. J. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38:293-306.

Bailey, N. T. J. 1952. Improvements in the interpretation of recapture data. Journal of Animal Ecology 21:120-127.

Brown, C. J. D. 1943. Age and growth of Montana grayling. The Journal of Wildlife Management 7:353-364.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological censuses. University of California Publications in Statistics 1:131-160.

Clark, R. A. 1992. Influence of stream flows and stock size on recruitment of Arctic grayling (*Thymallus arcticus*) in the Chena River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 49(5): 1027-1034.

Cochran, W. G. 1977. Sampling techniques, third edition. John Wiley and Sons, New York.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

DeCicco, A. L. 1990. Seward Peninsula Arctic grayling study 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-11, Anchorage.

DeCicco, A. L. 1991. Seward Peninsula Arctic grayling study, 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-24, Anchorage.

DeCicco, A. L. 1992. Assessment of selected stocks of Arctic grayling in streams of the Seward Peninsula, Alaska during 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-13, Anchorage.

DeCicco, A. L. 1993 Assessment of selected stocks of Arctic grayling in streams of the Seward Peninsula, Alaska during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-36, Anchorage.

DeCicco, A. L. 1994. Assessment of selected stocks of Arctic grayling in streams of the Seward Peninsula, Alaska during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-12, Anchorage.

DeCicco, A. L. 1995 Assessment of Arctic grayling in selected streams and a survey of Salmon Lake, Seward Peninsula, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-19, Anchorage.

DeCicco, A. L. 1996 Assessment of Arctic grayling in selected streams of the Seward Peninsula, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-21, Anchorage.

DeCicco, A. L. 1997 Assessment of Arctic grayling in selected streams of the Seward Peninsula, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 95-19, Anchorage.

DeCicco, A. L. 2000. Stock assessment of Arctic grayling in the Fish River, Seward Peninsula, Alaska 1999. Alaska Department of Fish and Game, Fishery Data Series No. 00-29, Anchorage.

REFERENCES CITED (Continued)

DeCicco, A. L. 2002a. Stock assessment of Arctic grayling in the Nome River and age validation of Arctic grayling in the Eldorado River, Seward Peninsula, Alaska 2000. Alaska Department of Fish and Game, Fishery Data Series No. 02-01, Anchorage.

DeCicco, A. L. 2002b. Fishery Management Plan for Arctic grayling sport fisheries along the Nome Road System, 2001–2004. Alaska Department of Fish and Game, Fishery Management Report No. 02-03, Anchorage.

DeCicco, A. L. 2004. Fishery management report for sport fisheries in the northwest Alaska management area, 2002-2003. Alaska Department of Fish and Game, Fishery Management Report No. 04-01, Anchorage.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

Gryska, A. D. 2001. Abundance and length and age composition of Arctic grayling in the Delta Clearwater River, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 01-27, Anchorage.

Gryska, A. D. 2004. Abundance and length and age composition of Arctic grayling in the Snake River, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 04-15, Anchorage.

Gryska, A. D. *In prep.* Vulnerability of Arctic grayling to the Brushkana Creek sport fishery. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

Howe, A. L., G. Fidler, and M. J. Mills. 1995. Harvest, catch, and participation in Alaska sport fisheries during 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-24, Anchorage.

Howe, A. L., G. Fidler, A. E. Bingham, and M. J. Mills. 1996. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-32, Anchorage.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001a. Participation, catch, and harvest in Alaska sport fisheries during 1999. Alaska Department of Fish and Game, Fishery Data Series No. 01-8, Anchorage.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001b. Revised Edition: Harvest, catch, and participation in Alaska sport fisheries during 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-29 (revised), Anchorage.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001c. Revised Edition: Harvest, catch, and participation in Alaska sport fisheries during 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-25 (revised), Anchorage.

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001d. Revised Edition: Participation, catch, and harvest in Alaska sport fisheries during 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-41 (revised), Anchorage.

Kruse, T. E. 1959. Grayling of Grebe Lake, Yellowstone National Park, Wyoming. U.S. Fish and Wildlife Service Fishery Bulletin 59:307-351.

Merritt, M. F. 1989. Age and length studies and harvest surveys of Arctic grayling on the Seward Peninsula, 1988. Alaska Department of Fish and Game, Fishery Data Series No. 79, Juneau.

Mills, M. J. 1989. Alaska statewide sport fisheries harvest report (1988). Alaska Department of Fish and Game, Fishery Data Series No. 122, Juneau.

Mills, M. J. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-44, Anchorage.

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-58, Anchorage.

REFERENCES CITED (Continued)

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-40, Anchorage.

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-42, Anchorage.

Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-28, Anchorage.

Northcote, T. G. 1995. Comparative biology and management of Arctic and European grayling (*Salmonidae*, *Thymallus*). Reviews in Fish Biology and Fisheries, 5:141-194.

Ridder, W. P. 1998. Radiotelemetry of Arctic grayling in the Delta Clearwater River 1995 to 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-37, Anchorage.

Ridder, W. P. and A. D. Gryska. 2000. Abundance and composition of Arctic grayling in the Delta Clearwater River 1999. Alaska Department of Fish and Game, Fishery Data Series No. 00-38, Anchorage.

Robson, D. S., and H. A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Transactions of the American Fisheries Society 93:215-226.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, second edition. Charles Griffin and Co., Ltd. London, U.K.

Tack, S. L. 1973. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress, 1972-1973, Project F-9-5, 14(R-1).

Tack, S. L. 1980. Distribution, abundance, and natural history of the Arctic grayling in the Tanana River drainage. Alaska Department of Fish and game, federal aid in Fish Restoration, Annual Performance Report, 1971-1980. Project F-9-12, 21(R-1).

Thompson, S. K. 1987. Sample size for estimating multinomial proportions. The American Statistician 41(1):42-46.

U. S. Census Bureau. 2001. 2000 Census PL94-171 Redistricting File.

Walker, R. J., C. Olnes, K. Sundet, A. L. Howe, and A. E. Bingham. 2003. Participation, catch, and harvest in Alaska sport fisheries during 2000. Alaska Department of Fish and Game, Fishery Data Series No. 03-05, Anchorage.

APPENDIX A. SAMPLING SCHEDULE AND CATCH STATISTICS

Appendix A1.–Sampling schedule and catch statistics by gear type for the Pilgrim River, 2002.

Date	Section		
	1&2	**3&4**	**5&6**
8/6/2002	A (12; 2)[a]		
8/7/2002	A (43; 3)	A (49; 0)	
8/8/2002		A (25; 0)	A (0; 4)
8/9/2002			A (1; 2)
8/10/2002		No sampling	
8/11/2002		No sampling	
8/12/2002	B (17; 0)		
8/13/2002	B (14; 8)	B (8; 25)	
8/14/2002		B (7; 13)	B (0; 9)
8/15/2002		B (0; 4)	

Crew A was composed of personnel 1 & 2
Crew B was composed of personnel 1, 3, & 4
[a] Values in parentheses indicate number of Arctic grayling caught by gear type (seine; hook-and-line gear).

APPENDIX B. DATA FILE LISTING

Appendix B1.-Data files for all Arctic grayling captured in the Pilgrim River, August 2002.

Data file	Description
Pilgrim River 2002 Data.csv	Sample data from August 6 - 15, 2002.
Pilgrim Final Analysis 2002 .xls	Data and analysis in excel spreadsheet

Note: Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1565

APPENDIX C. METHODS FOR TESTING ASSUMPTIONS OF THE PETERSEN ESTIMATOR AND ESTIMATING ABUNDANCE AND AGE AND SIZE COMPOSITION

Appendix C1.-Methodologies for alleviating bias due to size selectivity.

	Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]		
	Fail to reject H_o	Reject H_o
	Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event.	
Case III[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]		
	Reject H_o	Reject H_o
	Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first Kolmogorov-Smirnov (K-S) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Estimate length and age distributions from second event and adjust these estimates for differential capture probabilities.

Appendix C2.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test For Complete Mixing[a]

Section	Section Where Recaptured				Not Recaptured
Where Marked	**1**	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
s					

II.-Test For Equal Probability of capture during the first event[b]

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked $(n_2\text{-}m_2)$				

III.-Test for equal probability of capture during the second event[c]

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

[a] This tests the hypothesis that movement probabilities (θ) from section i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among river sections: H_0: $\Sigma_i a_i\theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among the river sections: H_0: $\Sigma_j\theta_{ij}p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

Appendix C3.–Equations for estimating length and age compositions and their variances for the population.

The diagnostic tests indicated that there was no size selective sampling during either event (Case I, Appendix C1). Therefore, stratification by size was not necessary and population compositions of lengths and ages were estimated using measurements from both sampling events. The proportions of Arctic grayling within each age or length class *k* were estimated:

$$\hat{p}_k = \frac{n_k}{n} \tag{C-1}$$

where:

n_k = the number of Arctic grayling sampled within age or length class *k* and,

n = the total number of Arctic grayling sampled.

The variance of each proportion was estimated as (from Cochran 1977):

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{C-2}$$

The abundance of Arctic grayling in each length or age category, *k*, in the population was then estimated:

$$\hat{N}_k = \sum_{k=1}^{s} \hat{p}_k \hat{N}, \tag{C-3}$$

where:

$\hat{N}$ = the estimated overall abundance; and,

s = the number of age or length classes.

The variance for $\hat{N}_k$ was then estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] \approx \sum_{k=1}^{s} \left(\hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}[\hat{N}]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}[\hat{N}]\right). \tag{C-4}$$

Appendix C4.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

The Bailey-modified Petersen estimator (Bailey 1951 and 1952) was used because the sampling design called for a systematic downstream progression, fishing each pool and run and attempting to subject all fish to the same probability of capture while sampling with replacement. The Bailey modification to the Petersen estimator may be used even when the assumption of a random sample for the second sample is false when a systematic sample is taken provided:

1) there is uniform mixing of marked and unmarked fish; and,
2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

The abundance of Arctic grayling was estimated as:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \tag{C-5}$$

where:

n_1 = the number of Arctic grayling marked and released alive during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

m_2 = the number of Arctic grayling marked in the first event that were recaptured during the second event; and,

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \tag{C-6}$$

APPENDIX D. HISTORIC DATA SUMMARY

Appendix D1.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1990.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
270 – 299	0	0.00	0.00		
300 – 324	7	0.07	0.03	120	52
325 – 349	5	0.05	0.02	86	42
350 – 374	16	0.16	0.04	275	92
375 – 399	11	0.11	0.03	189	70
400 – 424	22	0.22	0.04	378	117
425 – 449	20	0.20	0.04	343	109
450 – 474	15	0.15	0.04	258	88
475 – 499	2	0.02	0.01	34	25
500 – 525	2	0.02	0.01	34	25
Total	100			1,717	

Appendix D2.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1991.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
270 – 299	40	0.13	0.02	147	34
300 – 324	44	0.14	0.02	162	37
325 – 349	37	0.12	0.02	136	32
350 – 374	65	0.21	0.02	239	51
375 – 399	42	0.13	0.02	155	36
400 – 424	18	0.06	0.01	66	19
425 – 449	41	0.13	0.02	151	35
450 – 474	25	0.08	0.02	92	24
475 – 499	1	<0.01	<0.01	4	4
500 – 525	0				
Total	313			1,152	

Appendix D3.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1992.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 – 299	76	0.21	0.02	228	40
300 – 324	58	0.16	0.02	174	33
325 – 349	45	0.12	0.02	135	27
350 – 374	50	0.14	0.02	150	29
375 – 399	56	0.15	0.02	168	32
400 – 424	44	0.12	0.02	132	27
425 – 449	22	0.06	0.01	66	17
450 – 474	14	0.04	0.01	42	12
475 – 499	5	0.01	0.01	15	7
500 – 524	0				
Total	370			1,108	

Appendix D4.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1993.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 – 299	46	0.17	0.02	104	20
300 – 324	34	0.13	0.02	77	16
325 – 349	43	0.16	0.02	97	19
350 – 374	47	0.18	0.02	106	20
375 – 399	40	0.15	0.02	90	18
400 – 424	23	0.09	0.02	52	13
425 – 449	17	0.06	0.02	38	10
450 – 474	113	0.04	0.01	25	8
475 – 499	2	0.01	0.01	5	3
500 – 524	0				
Total	263			595	

Appendix D5.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1994.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 – 299	32	0.24	0.04	88	24
300 – 324	7	0.05	0.02	19	8
325 – 349	18	0.13	0.03	50	15
350 – 374	17	0.13	0.03	47	15
375 – 399	30	0.22	0.04	83	23
400 – 424	15	0.11	0.03	41	14
425 – 449	9	0.07	0.02	25	10
450 – 474	6	0.04	0.02	17	7
475 – 499	2	0.01	0.01	6	4
500 – 524	0				
Total	136			374	

Appendix D6.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1995.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 – 299	27	0.15	0.03	101	25
300 – 324	21	0.12	0.02	79	21
325 – 349	17	0.10	0.02	64	18
350 – 374	14	0.08	0.02	53	16
375 – 399	13	0.07	0.02	49	16
400 – 424	38	0.22	0.03	143	32
425 – 449	30	0.17	0.03	113	27
450 – 474	13	0.07	0.02	49	16
475 – 499	2	0.1	0.01	8	5
500 – 524	0				
Total	175			657	

Appendix D7.–Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 1996.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 – 299	3	0.02	0.01	13	8
300 – 324	1	0.01	0.01	4	4
325 – 349	6	0.05	0.02	26	11
350 – 374	12	0.10	0.03	52	16
375 – 399	19	0.15	0.03	83	21
400 – 424	24	0.20	0.04	104	24
425 – 449	27	0.22	0.04	117	26
450 – 474	23	0.19	0.04	100	23
475 – 499	8	0.07	0.02	35	13
500 – 524	0				
Total	123			534	

Appendix D8.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 270 mm FL, in a 9.0-km index section of the Pilgrim River, 2002.

Length Class (mm FL)	n	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$
270 - 299	3	0.01	0.01	10	6
300 - 324	8	0.04	0.01	26	10
325 - 349	22	0.10	0.02	72	20
350 - 374	38	0.17	0.02	124	30
375 - 399	49	0.22	0.03	160	37
400 - 424	47	0.21	0.03	154	36
425 - 449	37	0.16	0.02	121	30
450 - 474	20	0.09	0.02	66	19
475 - 499	2	0.01	0.01	7	5
500 - 524	0				
Total	226			740	